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RADIOACTIVE DECAY CHARACTERISTICS OF FALLOUT AND GAMMA RADIATION FIELDS

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Two basic types of decay measurements were made on residual activities from Operation REDWING:

1. Photon, by NaI scintillation detectors in the laboratory.

2. Gamma ionization, utilizing 4-pi ionization chambers in the laboratory; time intensity recorders mounted on three ships, two barges, and How Island; and surveys over an extended plane on How Island with Cutie Pie and T1B radiacs.

The samples for the lab measurements came from aircraft filter papers, i.e. the Standard Airborne Sample; Incremental Trays, containing 3" diameter greased discs, exposed for various times during fallout; and total fallout trays, some 2 ft^2 in area.

The reasons were fourfold for making these measurements:

1. To provide corrections of sample activities to a common counting time.

2. To obtain estimates of the ionization rates and rates of decay over extended land surfaces.

3. To obtain information on the extent of fission product fractionation, and capture to fission ratios of device and environmental materials.

4. To check the possibility of any gross changes in radiochemical composition of the fallout with time at a given location.

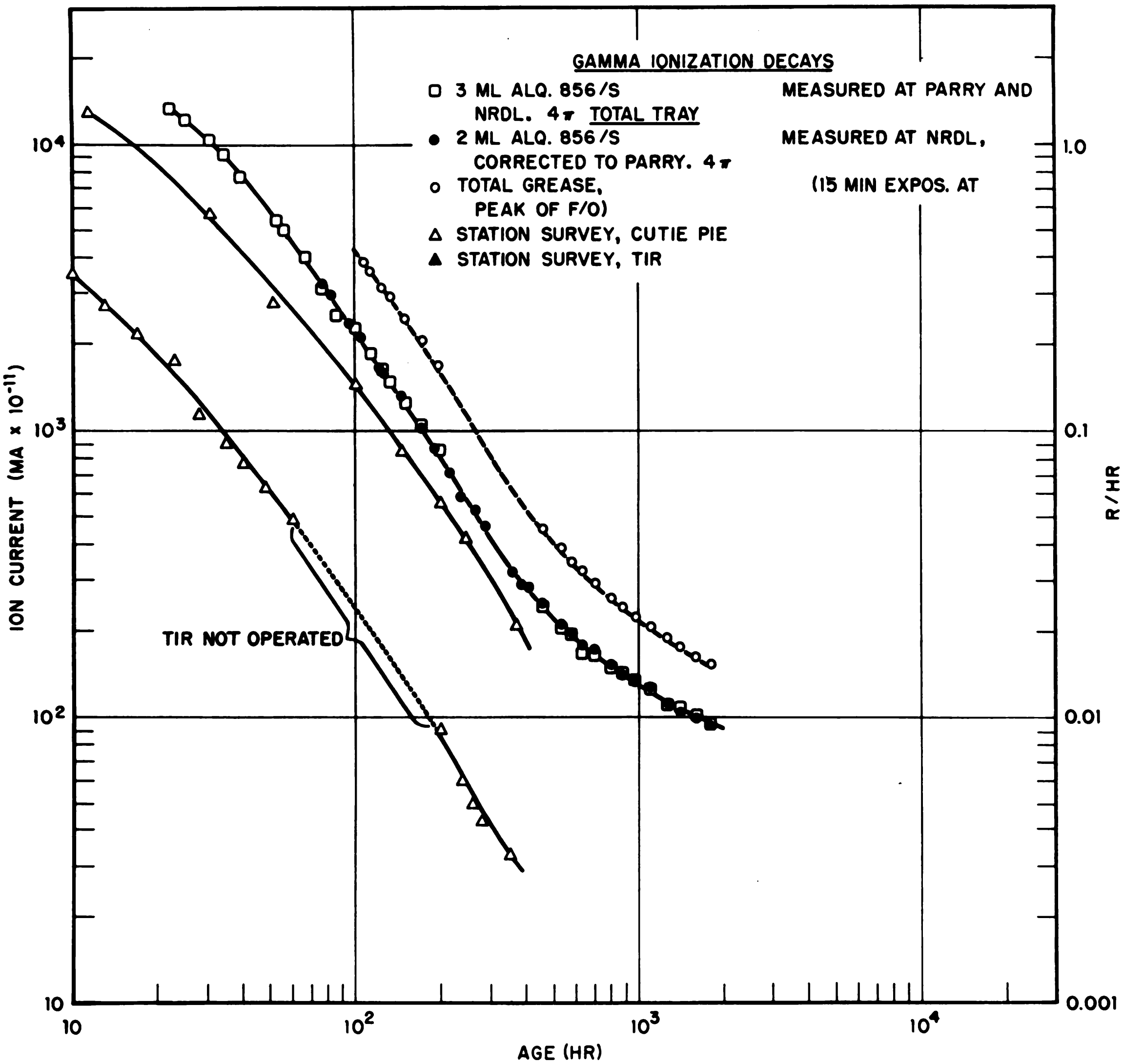
Figure 1 illustrates a series of ionization decays taken on How Island fallout. The four curves are labeled as to sample source and place and method of measurement. It will be noticed that all are identical with the exception of the Cutie Pie decay, which may be due to some differency in energy response of this instrument.

After one of the shots, a series of photon decay measurements was made on five incremental trays exposed for various periods during the fallout. All were identical within a few percent over the measurement period of a few hours to approximately twenty five days. Individual particles from these trays, however, showed a fair amount of variation from eachother. The implication is that in the aggregate, there is no significant variation of radiochemical composition with time at a given place.

The variations in photon decay observed on samples collected at various points in the fallout field are illustrated in figure 2 and the normalized curves are compared in figure 3.

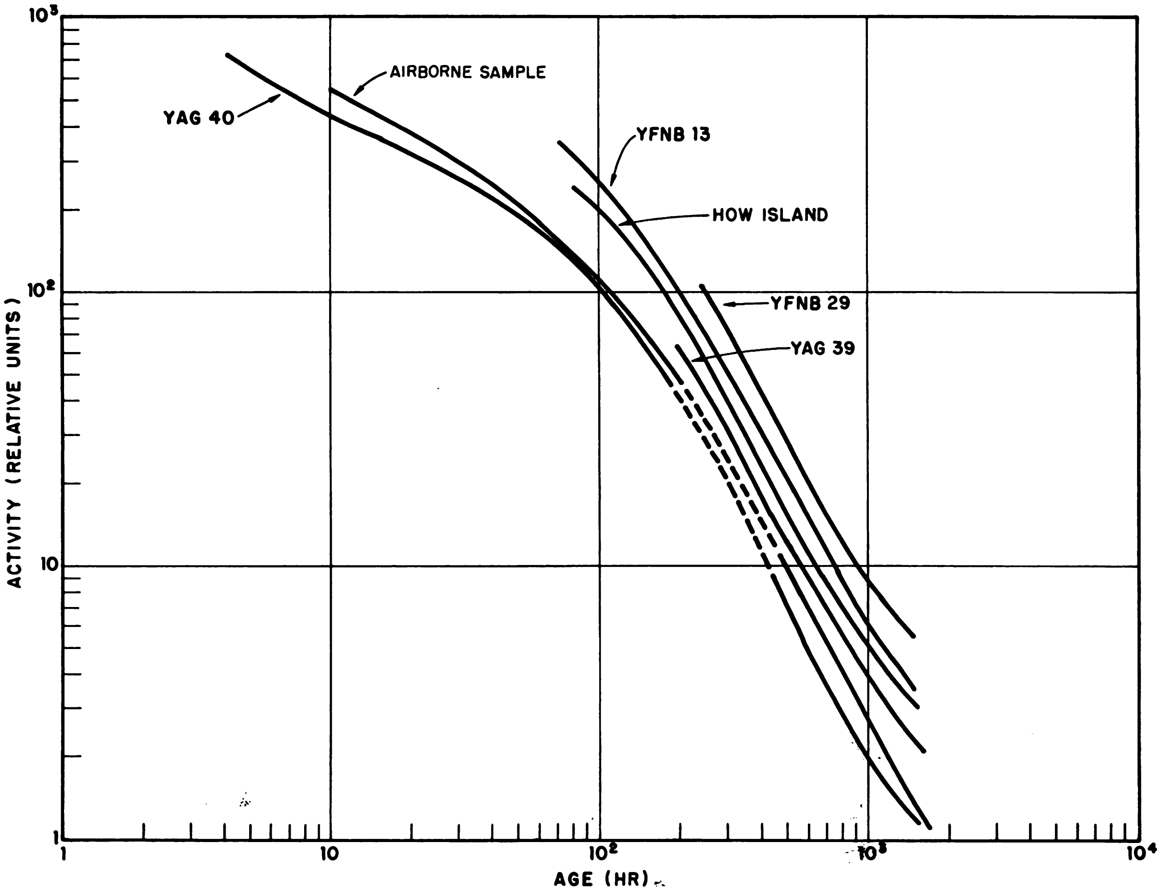
Finally, figure 4 shows the ionization decays of Standard Airborne Samples from four different events. It is evident that all differ from each other. Curve D approximates the $t^{-1.2}$ decay rate very closely, whereas the other curves range from $t^{-0.9}$ to $t^{-1.63}$. It is seen that appreciable errors can result in dosage estimates based on the $t^{-1.2}$ law, which applies only to fission products.

In summary, the present picture indicates that fractionation of fission product and induced activities in the fallout can occur to an appreciable degree, as demonstrated by these curves, other decay curves on single particles, gamma spectrometry, and measurements of capture to fission ratios for various induced activities. The general findings during Operation REDWING do not differ significantly from similar findings during earlier test series. It is hoped that a thorough analysis of these measurements will increase our understanding of the mechanism of particle formation and contamination.



GAMMA IONIZATION DECAYS

FIG. 1



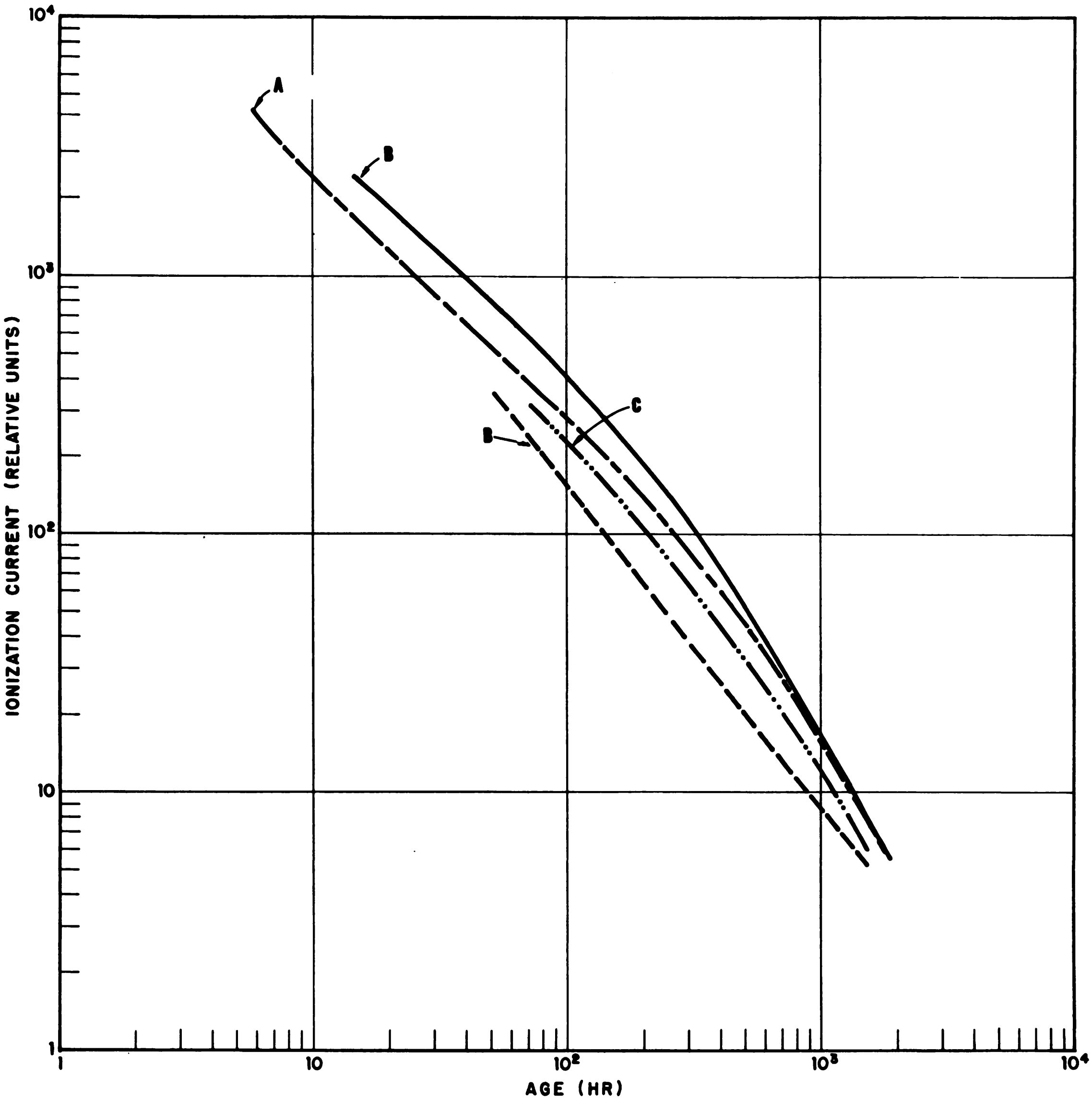
PHOTON DECAYS. NaI DETECTOR

FIG. 2

FIG. 3

RELATIVE PHOTON DECAY RATES, PER CENT

Age (Hours)	How Island	YFNB 13	YFNB 29	YAG 40	YAG 39	Airborne Sample
10	-	-	-	93	-	403
20	-	-	-	97	-	280
40	-	-	-	104	-	183
100	78	86	-	104	-	828
200	72	81	-	97	75	35.1
400	69	79	72	88	73	10.8
650	71	80	71	77	77	4.48
1000	82	87	81	84	83	2.01
1500	100	100	100	100	100	1.00



4π GAMMA IONIZATION DECAYS OF STANDARD AIRBORNE SAMPLES

FIG. 4

For Classified Papers:
See Volume 2 of Symposium Proceedings

BRIEF SUMMARY OF GAMMA RADIATION SPECTRA FROM RESIDUAL RADIATION SOURCES FOLLOWING A NUCLEAR DETONATION

Dr. R. L. Mather, USNRDL

The following brief summary is extracted from research carried out by members of the U. S. Naval Radiological Defense Laboratory, including Dr. C. S. Cook, Mr. F. M. Tomnovec, Mr. W. E. Thompson, LT R. F. Johnson, Mr. L. A. Webb, Mr. F. L. Bouquet and the author, and summarized in the Confidential RD documents listed in the references. The summary is intended to supplement or replace information in Chapter VIII of the Unclassified "Effects of Atomic Weapons (1950)" and is intended to be Unclassified. It was presented orally at the USNRDL Shielding Symposium, 18 October 1956. The research has been supported by the U. S. Navy Bureau of Ships and in part by the Armed Forces Special Weapons Project.

In the progress of a nuclear detonation both fission product and induced activities are produced in ratios which may depend on the details of the weapon construction and of its environment. Following the detonation these activities are dispersed and fractionated by physical and chemical phenomena influenced by terrain and meteorological conditions. These activities come to rest and create a residual radiation field which can be controlled by shielding. The effectiveness of the shielding will depend on the nature of this radiation field.

This Laboratory has been gathering empirical data on the nature of the radiation fields following various weapon detonations of the past several years from which one can say what the usually observed effects are and can say something about their customary variability.

The distribution of residual activities is typically in two parts; one symmetrical about ground zero and due to activities induced in the soil by the bomb neutrons and to activities deposited there by the fireball; the second elongated and downwind due to fallout from the bomb cloud.

The total gamma radiation intensity from mixed fission products decays with time in a fashion which is the sum of the exponential decays of the various nuclides in the mixture. The decay is usually empirically fitted by a negative power function of the time after detonation. The power is usually observed to be one and a fraction with some variation from shot to shot, from sample to sample of the same shot, from time to time on the same sample, and on the definition of the measure of intensity.

A group of us has been applying gamma-ray scintillation spectroscopy to samples of residual activities from a dozen or so shots exploded in the last three years. (References C-1, 2, 3, 4, 5; U-2) A sample of some of our recent data is shown in Figure 1, which is a pulse height spectra of pulses from a 4-inch diameter by 4-inch long NaI(Tl) crystal detector, but which, for purposes of this summary, may be called a gamma-ray photon spectra. Beneath this spectrum are the spectra of five nuclides or nuclide chains which are often identifiable in these spectra. The first three are induced activities and the last two are fission products. There are, of course, many other isotopes present, most of which seem to contribute unidentifiable lines in the region of 200 to 800 kev.

The first two induced activities are prominent in the soil around ground zero. The second and third can be formed from bomb materials which are intimately mixed with the fission products and deposited with the fallout from the bomb cloud.

These five isotopes tell most of the story in the time span from two hours to three months following the detonation. Each isotope becomes most prominent (to the extent of twenty to fifty per cent of the gamma ray intensity) in the spectra about 1.5 half-lives after the time of detonation.

At ten to twenty hours after the detonation, in those locations where Na^{24} is an important contribution, the very penetrating and biologically effective 2.8 Mev quanta may be found in abundance. Four days following the detonation the 105 kev quanta from Np^{239} generally constitutes a very large fraction of the quanta emitted but these quanta have relatively low penetration and biological effectiveness. Twenty days after, the quite penetrating and effective 1.6 Mev quanta from La^{140} is prominent. Two months after, the 750 kev radiation from $ZrNb^{95}$ dominates the spectra.

There appear to be real differences in the spectral composition of fallout radiation that are of the order of two to one for the contribution of individual gamma ray lives. These differences have been observed to be (a) characteristic of the weapon, (b) characteristic of the region of the fallout area, and (c) a characteristic of the individual fallout particle. There is insufficient information to make any consistant explanation of these variations.

Following the emission of the quanta by the radioactive nuclides the gamma-ray spectrum is considerably altered by compton scattering from materials which support and surround the residual radiation sources. The scattered radiation is continuous in its energy distribution but always less than the source energy. Usually the energy of the scattered quanta is less than 250 kev regardless of the energy of the source radiation.

Experimental measurements of radiation spectra have been made for the simple case of fallout on level land. The spectrum is a function of the direction of the radiation as shown in Figure 2. This data was taken nine days following the detonation (when the 105 kev Np^{239} line was very prominent) and shows the 20 to 300 kev region of the spectra.

The pronounced peak in the intensity of 105 kev radiation traveling in the horizontal direction (90°) is due to viewing this uniformly distributed source plane at grazing incidence where the effective radiation source strength per unit solid angle reaches a very large value. The most effective use of shielding in such a radiation field is to shield against radiation coming from slightly below the horizon.

The scattered radiation is more uniformly distributed in direction and for angles above the horizontal ($< 90^{\circ}$) the radiation is all from scattering. The 75 kev peak in the spectrum of radiation scattered down by the air is due to the degradation by multiple scattering of the 105 kev Np^{239} line.

The two extreme radiation spectra revealed by this information are (a) a field of 2.8 Mev quanta above induced soil activities near ground zero ten to twenty hours after the detonation and (b) the 40-100 kev air scattered radiation entering a freshly dug foxhole in a fallout area two to ten days after the detonation.

CONFIDENTIAL RD REFERENCES

C 1. F. L. Bouquet, W. E. Kreger, R. L. Mather and C. S. Cook, USNRDL-420.

C 2. C. S. Cook, R. F. Johnson, R. L. Mather, F. M. Tomnovec, and L. A. Webb, USNRDL-TR-32.

C 3. L. A. Webb, F. M. Tomnovec, R. L. Mather, R. F. Johnson, and C. S. Cook, USNRDL-TR-106.

C 4. C. S. Cook, R. L. Mather, A. J. Hodges, Jr., R. F. Johnson, R. A. Taylor and F. M. Tomnovec, ITR-1117.

C 5. W. E. Thompson et al, work in progress.

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U 1. Los Alamos Scientific Laboratory, "The Effects of Atomic Weapons", U. S. Government Printing Office, Washington, D. C. (1950), Chapter VIII.

U 2. R. L. Mather, R. A. Taylor and C. S. Cook, Nucleonics 14-8, 69 (August 1956).

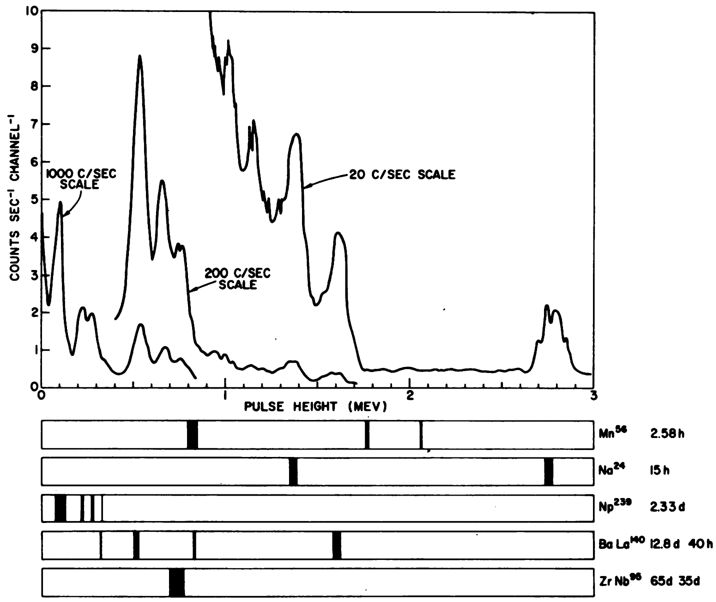


FIG. 1

NaI scintillation detector pulse-height distribution (approximately the gamma-ray photon spectrum) from a typical fallout sample with the gamma-ray line spectra from five nuclide or nuclide chains often identifiable in such spectra.

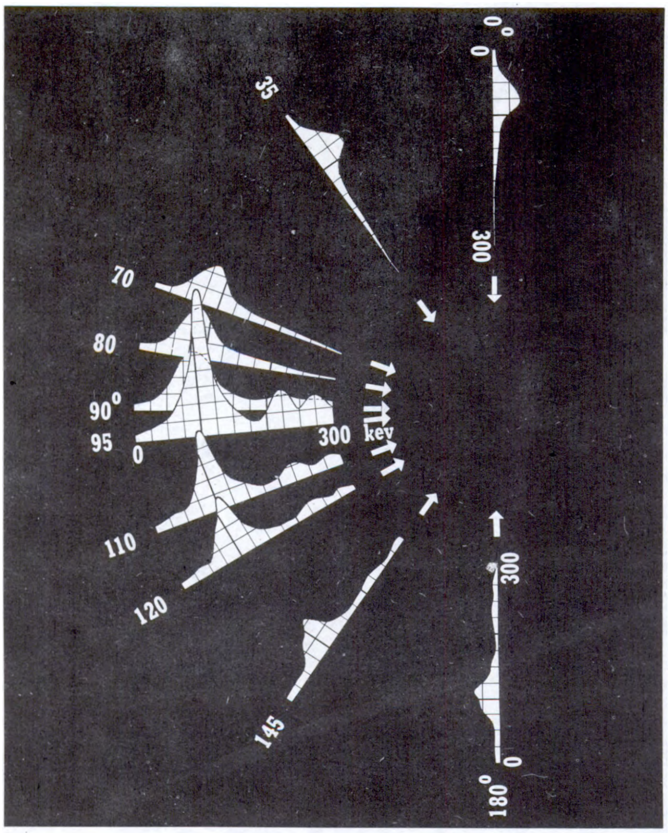


FIG. 2

Experimental 20-300 kev gamma-ray photon spectra observed in various directions above a flat field covered with fallout activities nine days after the detonation.

QUESTION - L. R. SOLON (AEC, NYOO):

Have you gotten any impression yet as to what fraction of a dose is contributed by gamma rays below 300 KEV, say between 100 and 300 KEV?

DR. MATHER:

Well, of course this is going to depend on time after the detonation. When the neptunium line is quite prominent, I would guess maybe fifty per cent is in this low-energy region, say below 300 KEV, and it varies of course from weapon to weapon. There is considerable variation. Sometimes we find a two-to-one variation in the contribution of a single line, say from one sample to another, from one weapon to another. We don't seem to be able to predict within a factor of 2.

"RADIATION SHIELDING CONSIDERATIONS IN UNDERGROUND SHELTERS"

CDR Arthur B. Chilton, CEC, USN
Bureau of Yards and Docks

I. Introduction.

This problem has received some attention in the past few months in the Bureau, in connection with several matters coming to our attention, requiring an understanding of how underground shelters, or shelters simulating this condition, can best be built to provide fall-out protection.

II. Idealized problem.

A. Situation studied.

(See slide 1)

Note: (1) Attenuation factor defined as ratio of dose at point ① to dose at point ②.

(2) Solution does not vary greatly with h, in practice, but for sake of computation, h taken as 8'.

(3) W initially assumed as wide enough so that infinite slab theory may be valid. Computation also made with finite roof areas, indicating when they have an effect on the answers.

(4) Roof consists here of concrete, at 147 lb./cu. ft. The results are applicable to earth or a combination of earth and concfete, on the basis that their effectiveness in in proportion to their densities. This is considered sufficiently accurate for practical purposes.

B. Dose inside.

(See slide 2)

For dose from area, dA,

$$dD = e^{-\mu_1 r} \cdot \frac{S\, dA}{r^2} \cdot B(\mu_1 r)$$

$$D_\infty = \int_\ell^\infty e^{-\mu_1 r}\, B(\mu_1 r)\, \frac{S}{r^2} \cdot 2\pi r \cdot dr$$

where

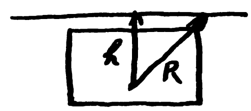
$$\mu_1 = \mu_a + \frac{t}{\ell}(\mu_e - \mu_a)\ .$$

Taking B = 1 + a $(\mu_1 r)$, substituting and computing: we get:

$$D_\infty = 2\pi S \left[-E_i(-\mu_1 \ell) + a \cdot e^{-\mu_1 \ell} \right]\ .$$

In computing the inside dose in a finite roof area case, it is easily shown that:

$$D_R = D_\infty(\ell) - D_\infty(R)$$



In applying these formulas, following assumptions made:

(1) 1 Mev γ-rays

(2) Mass abs. coeff. of air and concrete = .0635 $cm^2/gm.$, according to Gladys White.* We assume the same for earth.

(3) Density of concrete = 147 lb/ft.^{3}

Density of earth = 90 lb/ft.^{3} (assumed herein).

Density of air, at (20° C, 760mmHg), = .001205 gm/cm^3

(4) For computing the scattering coefficient a, I have used the values of Goldstein and Wilkins**, for dose build-up factors for point isotropic sources in homogenous, infinite scattering media. The values for 1 Mev photons in Aluminum are used. NRL experimental work has shown that in cavities such as this the experimental results can be approximated adequately by using the full coefficients for the infinite media case.

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* Gladys R. White, "X-Ray Attenuation Coefficients from 10 Kev to 100 Mev", NBS Rpt. 1003, May, 1952.

** H. Goldstein and J. E. Wilkins, Jr., "Calculations of the Penetration of Gamma Rays, Final Report", U.S. AEC Doc. NYo-3075, June 30, 1954.

In finding a, the number of mean-free-paths, on the average, is taken as 15% greater than at the thinnest point. Then B is obtained from the Goldstein and Wilkins tables, and a is computed from the relation $B = 1 + a(\mu_1 T)_{av} = 1 + 1.15\, a\, \mu_1 T$. Obviously a new value of a must be computed and used for each thickness of roof used.

I will not give the computation results of D as a function of T at this time.

C. Dose outside

(See slide 3)

This is computed on the following assumptions:

(1) H = 3 feet

(2) The fall-out radiation acts as if it were intimately mixed with the top 0.1" of paved surfaces or the top 1/2" of unpaved surfaces.*

(3) As modified by (2), infinite plane calculations are used. The figure shows that the computations to determine the dose here is a further extension of the equations for the previous case. It can be seen that:

$$dD = 2\pi S\left[-E_i(-\mu_1 t) + a \cdot e^{-\mu_1 t}\right] \cdot \frac{dt}{T}$$

Integrating over the total depth, 0 to T, we get

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* E. T. Sheffield- "Buffer Zones required in the Reclamation of Radiologically Contaminated areas", USNRDL Tech. Rpt. USNRDL-TR-31 of 14 Jan. 1955, quoting from internal NRDL Memo by A. Moskin.

$$D = \frac{2\pi S}{T} \left[-E_i(-\mu_2 H) \cdot \mu_2 H + E_i(-\mu_a H) \cdot \mu_a H + (1+a)\left(e^{-\mu_a H} - e^{-\mu_2 H}\right) \right],$$

where

$$\mu_2 = \mu_a + \frac{T}{H} \mu_e$$

In computing D for this case, we use the same data as before except for the scattering factor a. In this case, the number of mean-free-paths traversed by most of the photons is on the order of 1 or less, and the linear approximation $B = 1 + a(\mu_2 r)$ can provide a single value of a which is rather accurate from 0 to 1 mean-free-paths. Thus, a is almost constant in this case despite widely varying photon path lengths. The values of a selected is a matter of some guesswork. NRDL in similar cases has used 0.55*. I believe this is appropriate only for a slab shielding case with radiation normally incident, and my computations of the coefficient based on experimental work of Kennedy, Wyckoff and Snyder** at the Bureau of Standards seems to confirm that this is valid for slab shields. For infinite, homogeneous scattering media, the Goldstein and Wilkins data providessa value for a equal to 1.02.

I have discussed this matter with shielding specialists of NRL. They prefer to use a = 1.0. However, this situation appears to be somewhat in-between the two extremes and I have selected a value of a as 0.75. The exact value is really not of practical significance. For a = 0.75, the scattering contribution to the total dose is calculated to be 22.6%. Minor variations in a

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* C. F. Ksanda, S.M. Cohn, E.S. Shapiro, A. Moskin, H. C. Schmidt, and H. F. Hunter, "Gamma Radiations from Contaminated Planes and Slabs", USNRDL Tech. Memo No. 27, 19 Jan. 1955.

** P.J. Kennedy, H. O. Wyckoff, and W. A. Snyder, "Concrete as a Protective Barrier for X-Rays from Co^{60}", Jour. Res. Nat. Bu. Stds 44, 1950.

therefore do not effect the results very greatly. I think it worth-while to note, however, that Breslin and Solon* on the basis of experiments with an Co^{60} source estimate that in this case the scattering contribution should be about 20-25%. This agreement with our less well-founded guess is gratifying.

I made the computations both for earth surface and paved surface. The former is used as the standard. The latter case differs from the standard by only 3.4%.

Here again I will not quote the final computed results.

D. Attenuation factors

What is of interest is the Attenuation Factor as a function of slab thickness, taken as the ratio of the dosages computed in the two problems just described. These results are shown on the next slide. (See slide 4)

III. Preliminary conclusion from the attenuation factor computations.

(1) From about 4" to 20", a very close straight line approximation is valid on the semi-log scale, which is according to the following formula: Attn. Fact. = $0.45e^{-0.363T}$. This corresponds to a half-thickness of 1.91". Since in a practical case, the thickness would rarely be less than 4", the formula may be used with validity for practical purposes.

(2) It is hard to conceive of a fall-out shielding requirement outside the radii of other effects more severe than 1/3000. This would require a thickness of about 20" of concrete. This amounts to about 33" of earth at 90 lb./cu. ft.; or some combination of earth and concrete, such as 8" of concrete plus 20" of earth cover. One may as well round off the earth cover to the next higher foot, dirt being cheap, and exact density being often in doubt. An underground structure with thicknesses such as these would have

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* A. J. Breslin and L. R. Solon, "Fallout Countermeasures for AEC facilities, Preliminary Report, US AEC Doc. NYO-4682-A, Dec. 1955

a moderate degree of blast resistance, so that underground structures built to withstand a maximum fall-out hazard could probably be adapted without trouble to give very good protection from the combination of all effects up to about the 10 psi blast over-pressure line.

(3) Any thickness of cover greater than this maximum is probably beyond the point of diminishing returns and should be weighed carefully from an economic point of view. Additional earth cover may be inexpensive, and in some cases it is. However, one must consider that additional earth cover means a deeper excavation. Excavation is costly, and the ground-water level is down there somewhere to bother one. Also the static earth pressure is a dead load to be withstood, and the structure cost goes up thereby.

(4) We see here that a factor of safety of 2 is provided by about 2" more of concrete or about 3" more of earth, if the use of a factor of safety is warranted.

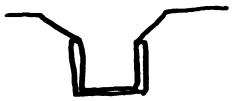
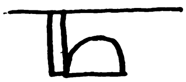
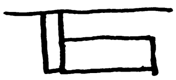
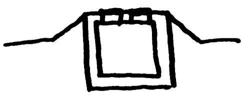
IV. Comparison with field tests.

Surprisingly enough, little or no good data from field tests exist, as far as I have been able to find, to provide a good comparison with theory. It would seem that in almost all cases, structures tested have been designed to test their structural resistance to blast pressures, with little thought of radiation considerations. Only after the structures have been designed and erected are the radiation specialists called in to provide instrumental readings and attenuation determinations. I will show a set of drawings of structures which were monitored by the Chem. Warfare Laboratory and Evans Signal Lab. personnel* after the Teapot ESS shot, which, being an underground shot, provided

* AEC Document ITR-1121, Prelim. Rpt. Op. Teapot, Proj. 2.7 "Shielding Studies" Prelim. Rpt., by Hendrickson, Engquist, Marmiroli, Grant, and Holland (SECRET)(RD).

a reasonable amount of fall-out. Most of these structures were originally built to determine resistance to underground blast effects from the Jangle shot, also an underground shot. The structures are illustrated in <u>Figure 1</u>, with related information summarized below.

TABLE I

STRUCTURE	SHAPE	ROOF ATTEN.	MEASURED ATTEN.
OCE 3.13		~ 0.1	Half-way up ladder, 0.47
BUDOCKS 3.17B		≪ .00001	Half-way up entrance, 0.05
AIR FORCE 3.23A		~ .00001	0.12 Center 0.02 Far end
AEC RECORDER SHELTER 3.28		~ .0057	0.09-0.18 Half-way up 0.61 Bottom 0.04 Far end

Note: Ref. pt. is av. between 3' and 1' above ground outside. Time = D + 8 days. What conclusions, theoretical or practical, can we draw from such data?

(1) We obviously get no check on accuracy of our shielding calculations.

(2) The amount of radiation coming through the roof in these cases is obviously so insignificant that other radiation source locations or leakage paths for the radiation are the factors of primary importance here. Such sources are either radioactive dust which has fallen in, or radiation scattered by the air through openings in the roof.

(3) Whatever the virtues of the structures may be, they are obviously not well suited for good fall-out radiation attenuation. A little intelligent effort in the design phase would have improved this situation a great deal, without greatly increasing the cost.

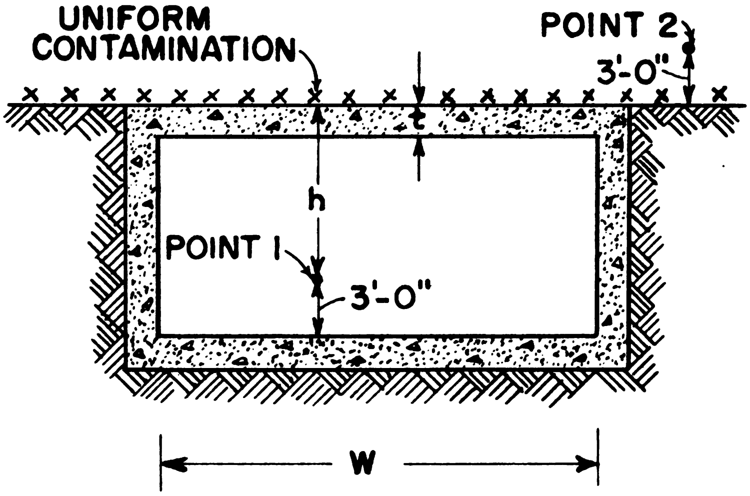
V. Possible improvement to shelter design.

(See Figures 2A and 2B)

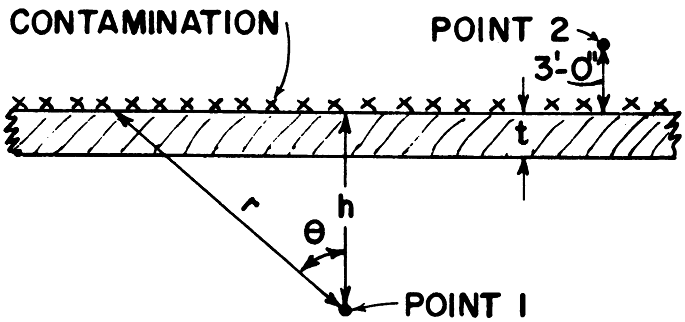
The ideas presented in these figures are tentative, and may be changed on further study. We are planning to incorporate many of them in new Bureau of Yards and Docks' structures tested in future atomic tests, and we feel that we have taken a significant step forward toward integration of all requirements and achieved a more well-balanced design.

VI. Acknowledgment.

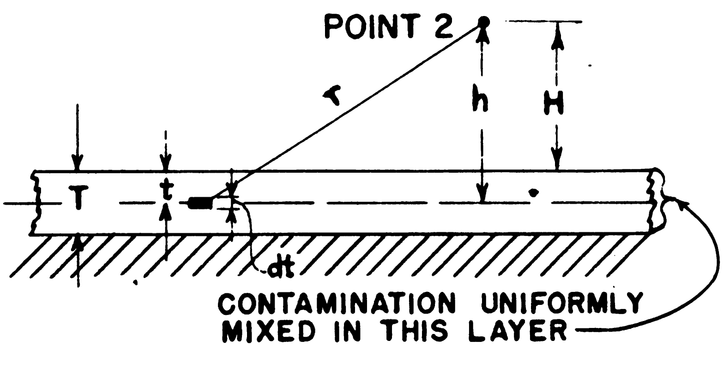
The assistance of CDR L. N. Saunders, CEC, USN, in making the necessary computations is appreciatively acknowledged.



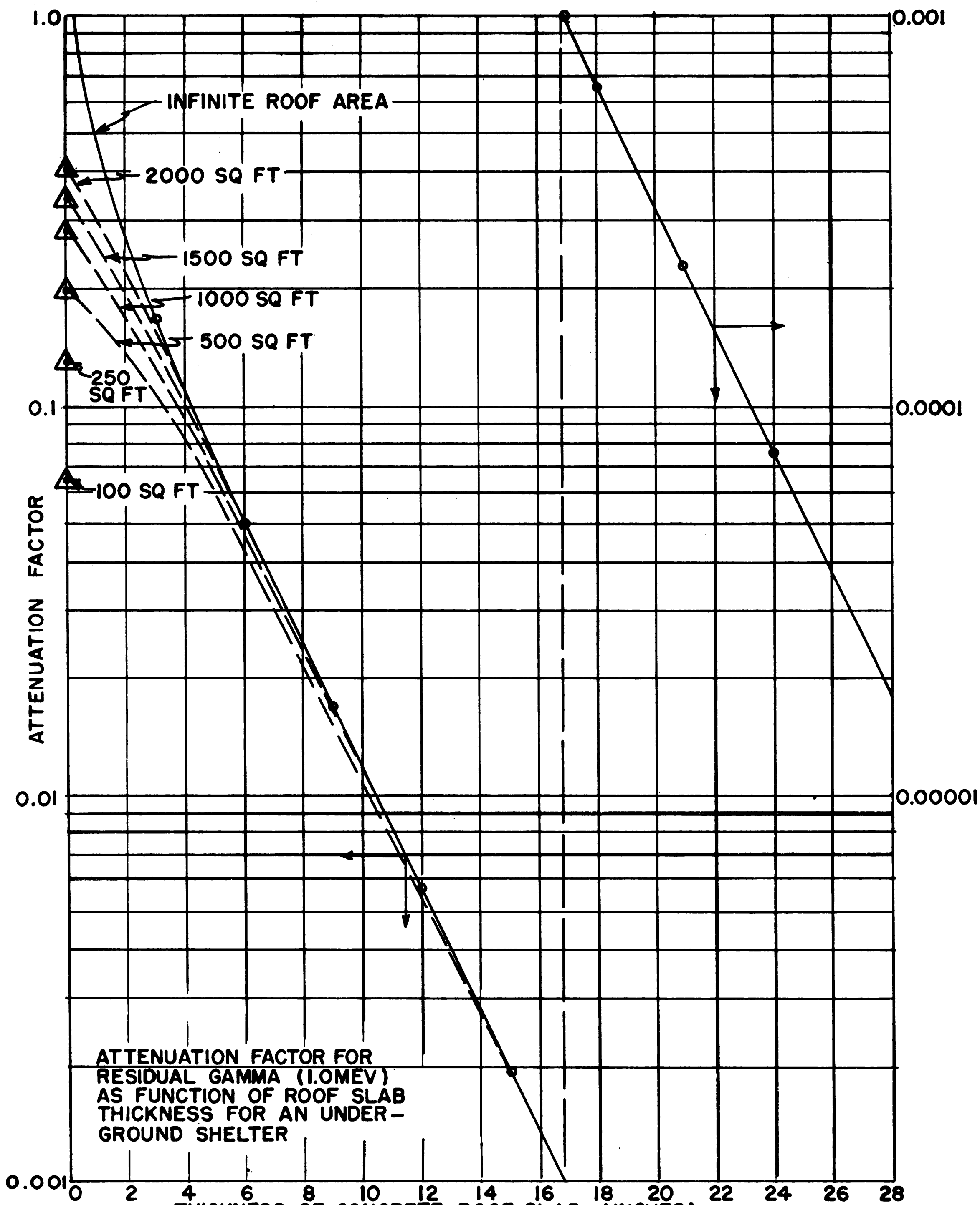
SLIDE 1



SLIDE 2



SLIDE 3



1.0
0.1
0.01
0.001
0.001
0.0001
0.00001
INFINITE ROOF AREA
2000 SQ FT
1500 SQ FT
1000 SQ FT
500 SQ FT
250 SQ FT
100 SQ FT
ATTENUATION FACTOR
ATTENUATION FACTOR FOR RESIDUAL GAMMA (1.0MEV) AS FUNCTION OF ROOF SLAB THICKNESS FOR AN UNDERGROUND SHELTER
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
THICKNESS OF CONCRETE ROOF SLAB (INCHES)

SLIDE 4

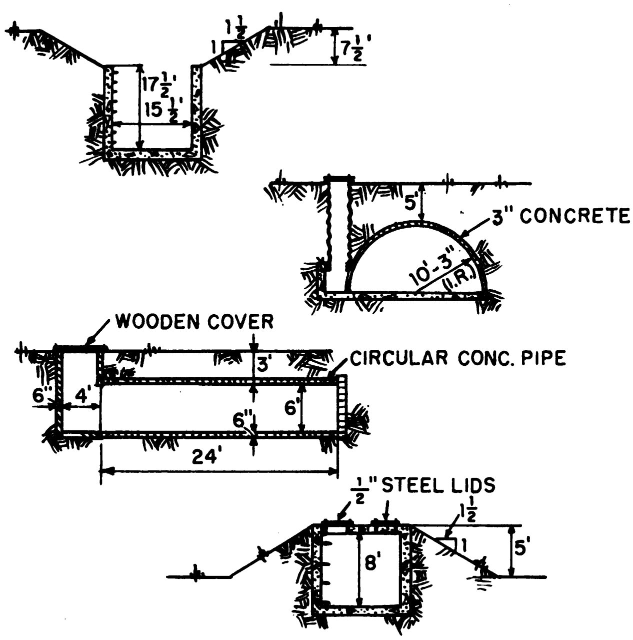


FIGURE 1

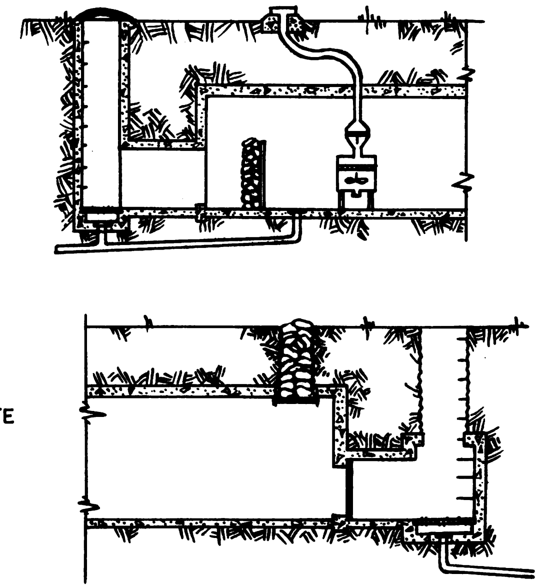
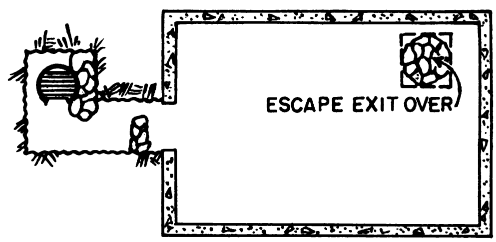


FIGURE 2A



PLAN

FIGURE 2B

SHIELDING PROPERTIES OF NAVAL BUILDINGS

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The possibility of nuclear warfare requires an appraisal of the shielding properties of existing naval buildings for nuclear radiations, which will indicate desirable modification or redesign. This report deals with the protection against fallout afforded by standard enlisted men's barracks. These barracks are three story buildings, 252 feet long and 34 to 40 feet wide. The floors and ceilings are made of concrete 3" to 8" thick. The long walls have windows comprising nearly half their area, with the construction of the remainder ranging from concrete eight inches thick to thin insulated aluminum spandrel in the different variations allowed. There is a small basement with outside entrance.

Preliminary study indicated that overall shielding is slight, so a method of calculation was sought which would give fair accuracy without undue effort, which would give the relative importance of the various sources of radiation and the components of the building, and which is capable of extension to cases of moderate shielding so that quantitative estimates of improvements could be made. The final results for barracks with concrete side walls show a reduction in gamma radiation of about a factor of four at the center of the building as compared to that outside at a height of three feet above ground, with little variation from floor to floor. This is only twice the reduction expected from a light frame building. In addition, biological effects from beta particles can be completely eliminated if doors and windows are kept closed to prevent contact with the fallout particles. The calculations indicate an increase in dose rate near the outside walls in general, as is expected from consideration of the simple limiting approximations of a uniformly contaminated spherical building and a ring source around a cylindrical building. The windows are the weakest point in the shielding by far, and the fallout on the ground near the building is the predominant source of radiation. The present basement is inadequate, but a well designed basement can give an additional reduction in dose rate by a factor of 20 to 30 which appears to be adequate for any fallout likely to be encountered. Modification of the basement appears to be the simplest and most economical means of providing protection against fallout, although adequate bomb shelters could mean that extensive modification is not essential.

The method of calculation involved integration over a simple source approximating that expected from fallout. Approximations were designed to minimize mathematical complexity without introducing large errors. The source was assumed to be a uniform, thin, infinite plane of contamination emitting isotropically, with equal source strengths per unit area on the ground, the roof, and one of the long walls. Each component (ground, roof, and wall) was computed separately to determine their relative importance; the wall component is expected to be a probable upper limit rather than the most likely amount. A single effective energy of 1 Mev was used for the gamma radiation in place of the complex spectrum of lower average energy, to give best accuracy for modified buildings providing fair shielding. With a complex spectrum, both the average energy and the effective energy vary with the penetration in shields of different thicknesses, but this approximation should give reasonable accuracy because of the comparatively small variation for the energies, shielding materials, and thicknesses of concern here. Disregard of self-absorption in the source (for both the dose rate inside the building and the comparison dose rate outside) was the second most important approximation. Possible variations in site and surroundings (buildings on hills and in valleys, with differing proportions of pavement, earth, trees, etc.) preclude a universal correction for self-absorption. This is believed to have little effect on the gross aspects of the solution. Better accuracy can be obtained if necessary by a linear approximation or an exponential approximation for self-absorption, or an appropriate combination; this will result in a slight change in the parameters of the problem rather than a change in the form of the solution. Also, radiation scattered into the ground was assumed to be completely absorbed. Dose build up factors were computed from a linear approximation to the values given by Goldstein and Wilkins[1] for aluminum, which is adequate for air, earth, concrete and other conventional building materials up to the maximum significant thickness of this problem. No correction need be applied for finite thickness of shield in the interior of buildings giving a fair amount of shielding.

Using the above approximations, the general expression for the dose rate D from a source of strength S per unit area with a build up $B = 1 + ar$

$$D = \int (SB/2r)\, e^{-\mu r}\, dr$$

reduces to the general form

$$D = (S/2)\left[-E_1(-\mu R) + (a/\mu)\, e^{-\mu R}\right]$$

where $-E_1(\mu R)$ is the exponential integral. To simplify the limits of integration, the central section of the building, the dormitory wings, the roof, and the wall were generally replaced by cylindrical units of equivalent area. Dose rates were calculated inside a phantom building with no attenuation in the walls and roof, inside a windowless concrete building, inside the actual barracks (both central section and wings), and inside modifications of the barracks. Dose rates were estimated near outside walls and at intermediate positions as well as at the center of the building. A numerical integration was used to determine the attenuation of the radiation from the ground source in the walls of a rectangular building and in the floors of upper stories; the results were not greatly different from the crude ones obtained by using an average wall thickness, for walls up to eight inches thick and angles up to 60°. All other results could be obtained directly from tabulations of the exponential integral and the negative exponential.

Some details of the general results given at the beginning are of interest. At the center of the barracks, the dose rate from the ground source is several times that of the roof and wall sources combined. Near a contaminated wall, the maximum contribution expected from the wall source is comparable to that from the ground source. In a windowless building and in a building with thin walls and roof, the contribution from the roof source is comparable to that from the ground source on the third floor, due partly to the shielding of the ground source by the floor in the windowless building. There is some difference in dose rate from floor to floor, but it is not large enough to be significant except in the phantom building. The dormitories have somewhat less shielding than the central section of the barracks, but the difference is unimportant. Most of the radiation in the present barracks comes through the windows. Unless there is drastic redesign or effective emergency measures for auxiliary shielding and decontamination, only small improvements in shielding can be expected. Ventilation as well as shielding needs attention.

The present basement is too small, and it is inadequately shielded because of the outside entrance, the fact that the upper part of the basement is above grade, and some transmission of radiation through the ceiling. Redesign could leave only the last source an important one. Increase of the ceiling thickness to twelve inches of concrete, with a well designed inside entrance and ventilating system, could give an overall reduction in dose rate by a factor of about a hundred. As an alternative, a windowless first floor (or sand-bagging of the windows) would give the same shielding in a basement with an eight inch thick ceiling. Toilet facilities on the first floor could still be used in conjunction with a basement shelter, and would thus be more economical than a separate shelter.

In addition to extra shielding, decontamination can help reduce the dose. However, decontamination should be carried out quickly (while the job is most difficult) if it is to be effective for continuous use of the barracks. It seems that perhaps inclusion of automatic devices for decontamination may be required since so much of the total dose is accumulated in the first few hours.

Our results have been converted to a "standard accumulated dose" in order to make them more meaningful. The standard accumulated dose is defined as that accumulated between four hours after attack (assuming fallout is complete then) and a time three months later. Using the standard $t^{-1.2}$ decay law for fallout, about half of the standard dose is accumulated in the first day. If fallout is complete by one hour after attack, the dose accumulated between one and three hours is about half the standard accumulated dose. The dose accumulated at a given location from three months after attack until years later is also about half of the standard accumulated dose. Thus our results in these terms are typical within a factor of two of what might be expected in almost all circumstances, and can be used in planning working schedules. The most important results are given in a table at the end of the paper, relative to a fallout of 1000 r/hr. at one hour. They indicate that the present barracks give some protection for fallouts of a few hundred roentgens per hour. If the fallout intensity at one hour is 1000 r/hr. or above, few survivors can be expected in the present barracks. For fallouts of intensity less than 100 r/hr at one hour, few casualties may be expected even without protection[2].

STANDARD ACCUMULATED DOSES IN VARIOUS STRUCTURES

Type of Structure	Thickness (Inches Concrete) Wall	Ceiling	Std. Acc. Dose (Roentgens)
None (3' above ground)			2800
Frame Bldg.	0	0	1500
Barracks (1st Floor)	8	6	750
Windowless Building	8	6	325
Windowless Building	12	6	250
New Basement		8	120
New Basement		12	30

References:

[1]Herbert Goldstein and J. Ernest Wilkins, Jr., "Calculations of the Penetration of Gamma Rays," Nuclear Development Associates, Inc., White Plains, New York, June 30, 1954; (NDA Report 15C-41, AEC Publication NYO-3075).

[2]Radiological Recovery of Fixed Military Installations, Table 2.2, p.9, NAVDOCKS TP-PL-13, August 1953.

"Shielding by Military Structures"

by E. S. Shapiro, USNRDL

The difficulty in assigning a shielding factor for a particular structure, or in predicting the optimal location inside a structure was discussed. The parameters that significantly influence the shielding factor and optimal location were analyzed. These parameters fall into two classes: (a) those that are determined by the structure itself; and (b) those that are independent of the structure. The former class includes: plan area, length-width ratio, height, number of floors, and type of construction. Included in the latter class are: receiver's height above ground, receiver's location at a given height, number and types of adjacent structures, surface roughness of area surrounding structure, and average gamma energy of the mixed fission products.

A technique was outlined whereby a planner, knowing these parameters, may estimate the maximum and minimum shielding factors of a building by using a small number of graphs and several arithmetical operations. This technique involves expressing the intensity I at the point of interest inside the structure as

$$I = I_G F_w F_f + I_R \qquad (1)$$

where I_G = intensity at point of interest above a rectangle (with same plan area as structure)

F_w = shielding factor of the structure's walls (which shield the point from surrounding radiation)

F_f = shielding factor of the structure's floors (which shield the point from surrounding radiation)

I_R = contribution of the contaminated roof to the total radiation field at the point of interest.

These four factors were evaluated for square structures and 8:1 structures with plan areas in the 1,000-250,000 sq. ft. range, and with heights up to 70 ft. Calculations indicate that at a fixed height inside a military structure of given plan area the intensity is bounded (in some order) by the intensities at the center of a square structure and the corner of an 8:1 structure.

I_G, I_R, F_w, and F_f were determined by evaluating

$$K = \iint_S I_0 \, B(E_0, \sum_i \mu_i x_i) \frac{e^{-\sum_i \mu_i x_i}}{4\pi x^2} \, dA \qquad (2)$$

over the contaminated region of interest, S, in which are distributed isotropic radioactive sources.

In Equation 2,

I_0 = source intensity = nE_0

n = number of quanta emitted per unit area per unit time

$B(E_0, \sum_i \mu_i x_i)$ = multiple scattering function

E_0 = quantum energy

μ_i = linear absorption coefficient of the i^{th} attenuating medium

x_i = path length traversed by the gamma rays in the i^{th} attenuating medium ($\sum x_i = x$)

x = distance from element of area dA in S to receiver.

When the integration is performed over the contaminated surroundings of the structure, then, in the absence of attenuating walls and/or floors, $K = I_G$; assuming attenuating floors, $K = F_f I_G$; and in the presence of attenuating walls, $K = F_w I_G$. Integrating over the contaminated roof, $K = I_R$.

I_G has been determined for cases in which the radioactive sources a) lie entirely on the surface of the surroundings; b) are buried beneath the surroundings; and c) are uniformly mixed with the surrounding soil. A comparison of the results of case c. with field data indicates that the effect of surface roughness on radiation intensity may adequately be compensated for in theoretical calculations by assuming the contaminant is uniformly mixed to some depth.

F_f was calculated for 1-½ in. wood floors and 8 in. concrete floors. On the basis of these calculations the following generalizations can be made.

(1) Inside a structure of nominal wood construction, the reduction in intensity due to floors will be nearly independent of the depth to which the contaminant of the surrounding ground is mixed or buried.

(2) At the center of a structure of nominal concrete construction, almost 100 per cent of the intensity will come from radiation not passing through floors.

(3) Floors are most effective in reducing intensity at the centers of structures, and least effective at the edges.

(4) At the center of a structure of nominal wood construction, given plan area, and given length-width ratio, the per cent reduction will be approximately the same for any height.

(5) At heights of less than 70 ft. and in corners of a structure of nominal wood or concrete construction, the reduction will be 5 per cent at most.

(6) The shielding effect by floors is greatest for square structures, and decreases with increasing length-width ratio.

On the basis of calculations made for several thicknesses of concrete and wood walls, the following generalizations can be made.

(1) Inside a structure with a small plan area, the reduction in intensity increases as the height increases.

(2) For nominal heights inside a structure with a large plan area, the reduction in intensity is nearly independent of height.

(3) The greatest per cent reduction in intensity is provided immediately adjacent to the wall; the smallest at the center of the structure.

(4) Reduction in intensity increases as the length-width ratio increases.

(5) Reduction in intensity increases as the depth to which the surrounding contaminant is mixed or buried increases.

(6) Reduction in intensity increases as plan area decreases.

This technique has been applied to several classes of buildings into which many military structures fall. The results are presented in the tables below. The center (square structure) and corner (8:1 structure) values given represent the bounds on the intensity that may be expected for any structure in the 1,000-250,000 sq. ft. range. For each point of interest two values are presented. The upper value corresponds to an average gamma ray energy of 1.25 Mev, and the lower value to 0.5 Mev.

SHIELDING FACTORS FOR BUILDINGS

2 - Story Buildings

Walls	Material Roof	Floors	Floor of Interest	Center	Corner
Wood	Wood	Wood	1st Floor	0.40	0.50
				0.40	0.60
			2nd Floor	0.70	0.50
				0.70	0.60
Concrete	Wood	Concrete	1st Floor	0.008-0.014	0.008-0.009
				0.03-0.05	0.03
			2nd Floor	0.30-0.60	0.10-0.20
				0.25-0.55	0.085-0.15
Concrete	Concrete	Concrete	1st Floor	>0.001-0.01	0.007
				0.003-0.03	0.01
			2nd Floor	0.003-0.01	0.006
				0.015-0.035	0.08
None	Concrete	Concrete	1st Floor	0.01-0.40	0.80
				0.025-0.45	0.80
			2nd Floor	0.003-0.30	0.60-0.70
				0.15-0.35	0.65

SHIELDING FACTORS FOR BUILDINGS

1 - Story Buildings at Various Heights

Material		10 Ft.		20 Ft.		40 Ft.	
Walls	Roof	Center	Corner	Center	Corner	Center	Corner
Wood	Wood	0.60-0.70 0.55-0.65	0.50-0.60 0.65-0.75	0.40-0.60 0.45-0.55	0.50-0.60 0.65-0.75	0.30-0.50 0.30-0.45	0.40-0.50 0.65-0.70
Concrete	Wood	0.30-0.60 0.25-0.55	0.10-0.20 0.075-0.15	0.10-0.60 0.10-0.50	0.03-0.20 0.040-0.15	0.05-0.40 0.055-0.45	0.01-0.10 0.015-0.12
Concrete	Concrete	0.003-0.01 0.015-0.045	0.008 0.012	0.003-0.1 0.015-0.040	0.008 0.012	0.003-0.01 0.015-0.035	0.008 0.012

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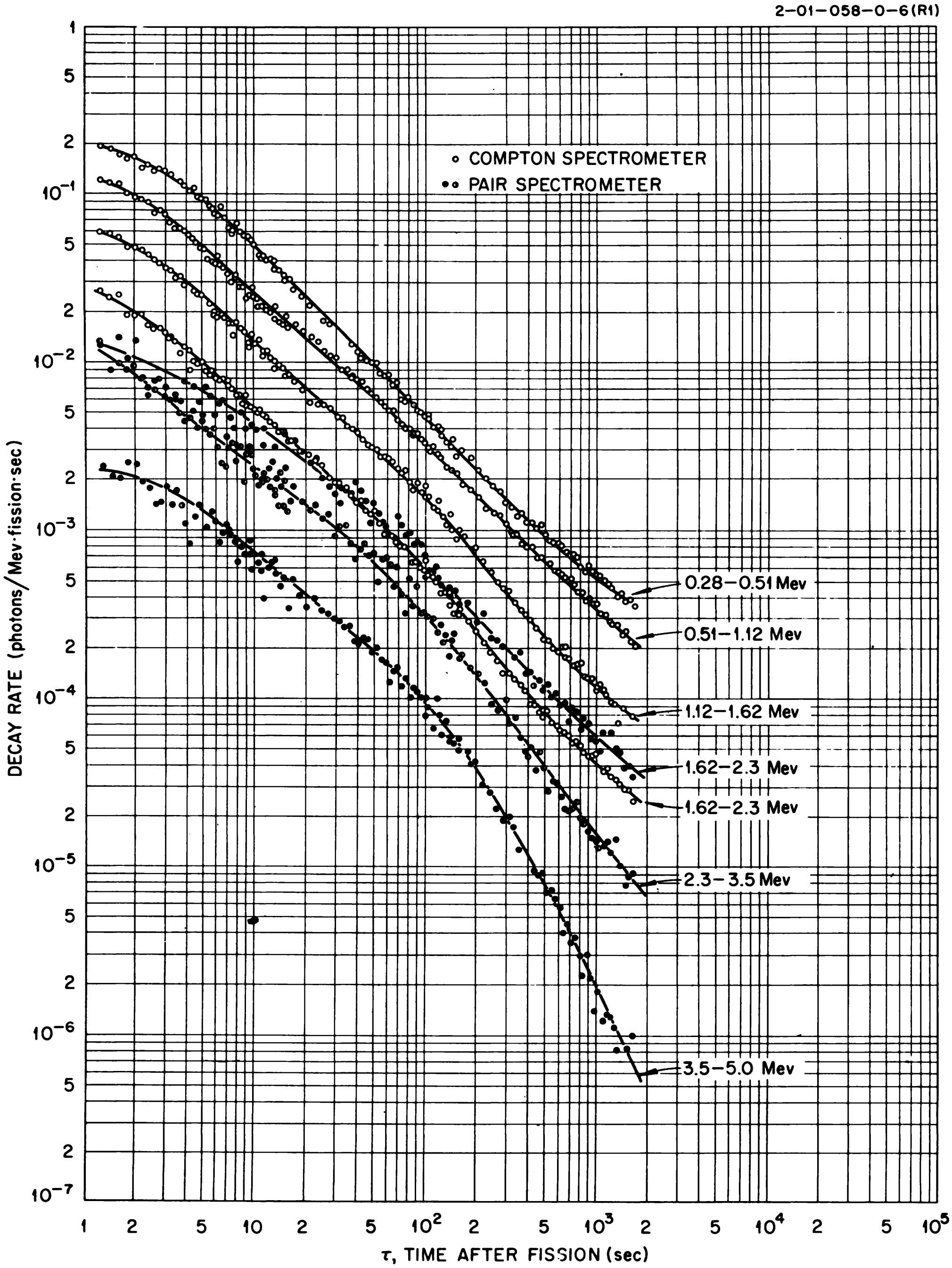

Fig. 17.1. Fission-Product Gamma-Ray Decay Rates as a Function of Time after Fission for Six Photon Energy Groups.

FIGURE 3

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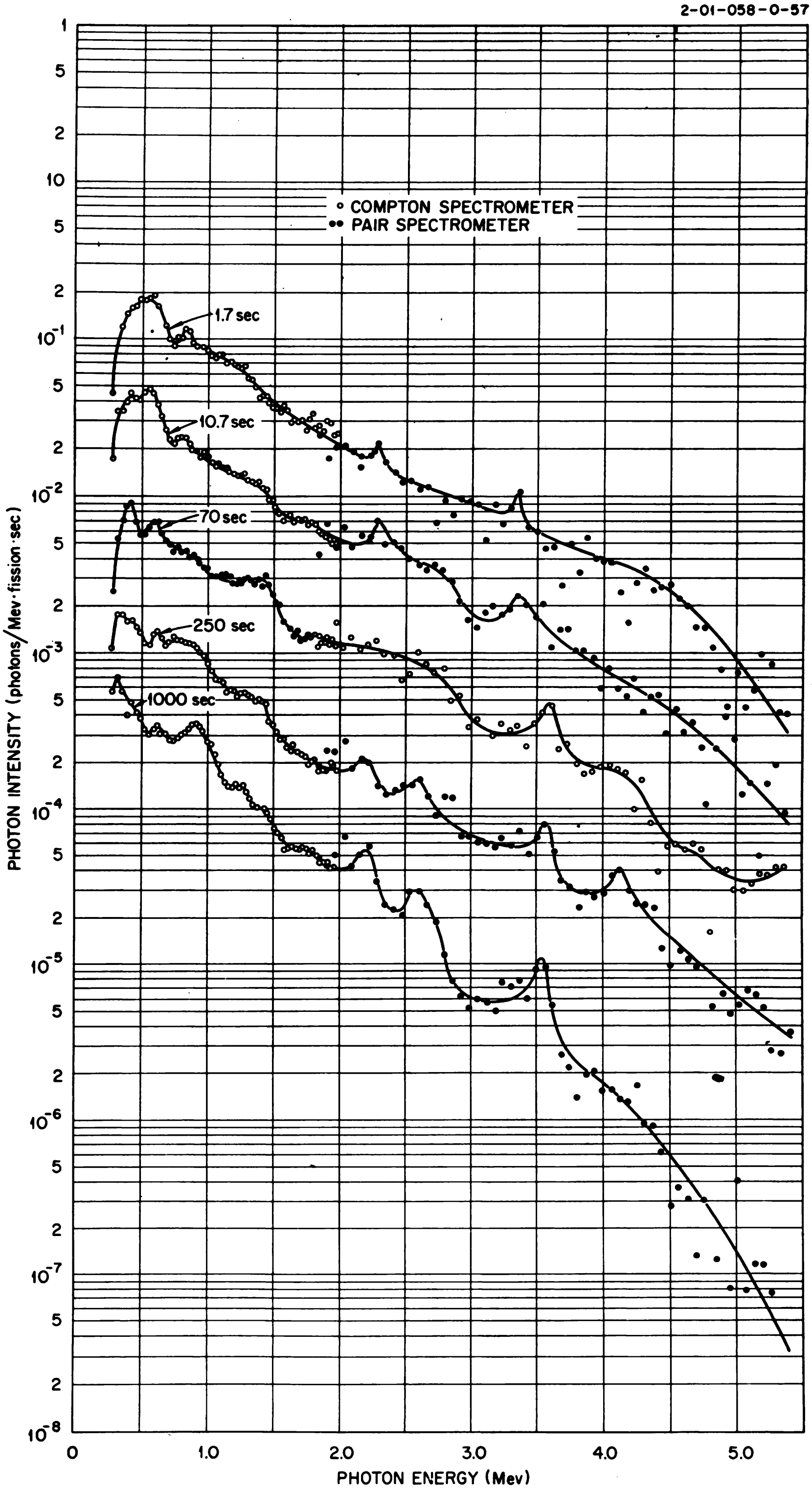

FIGURE 4

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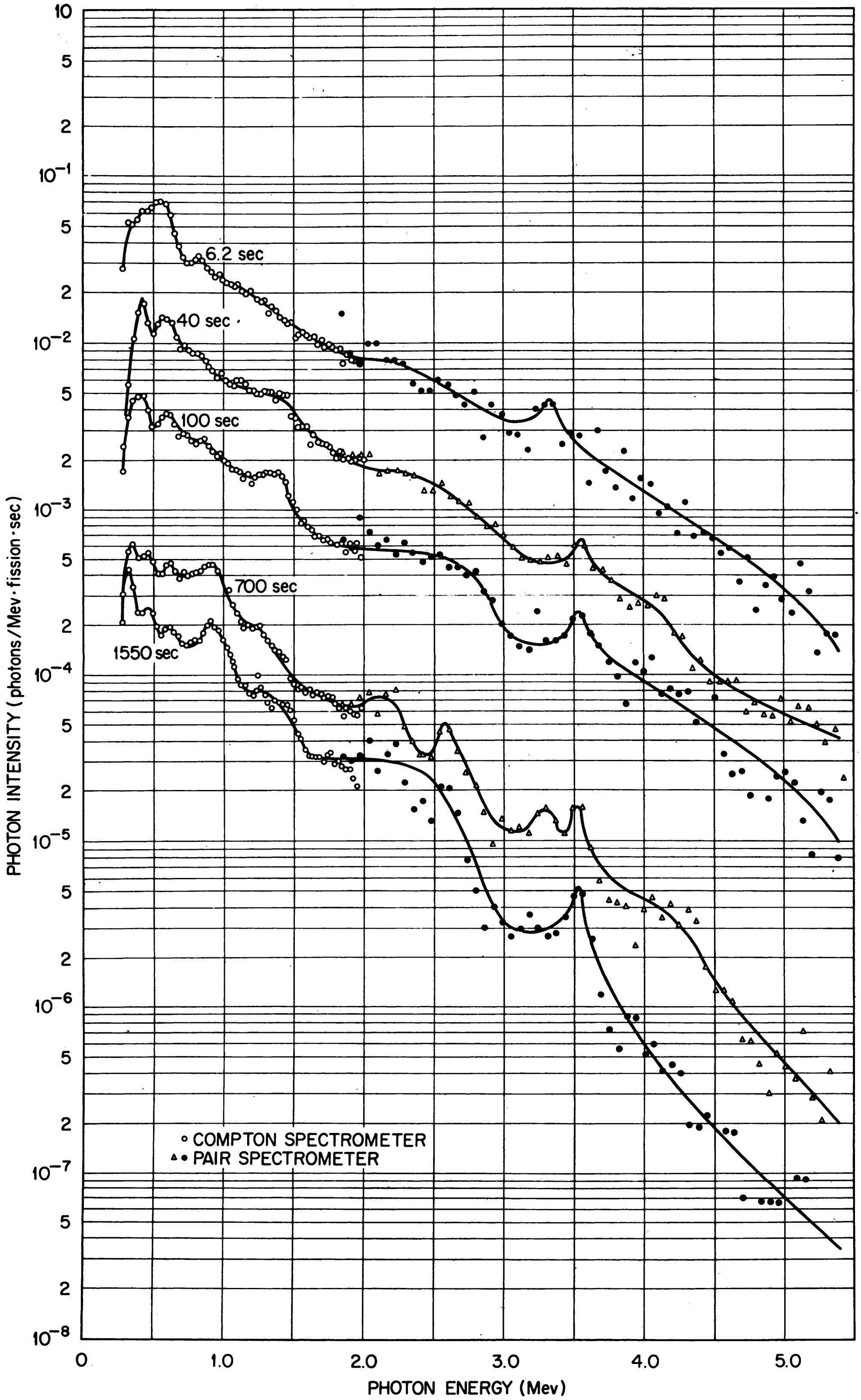

FIGURE 5

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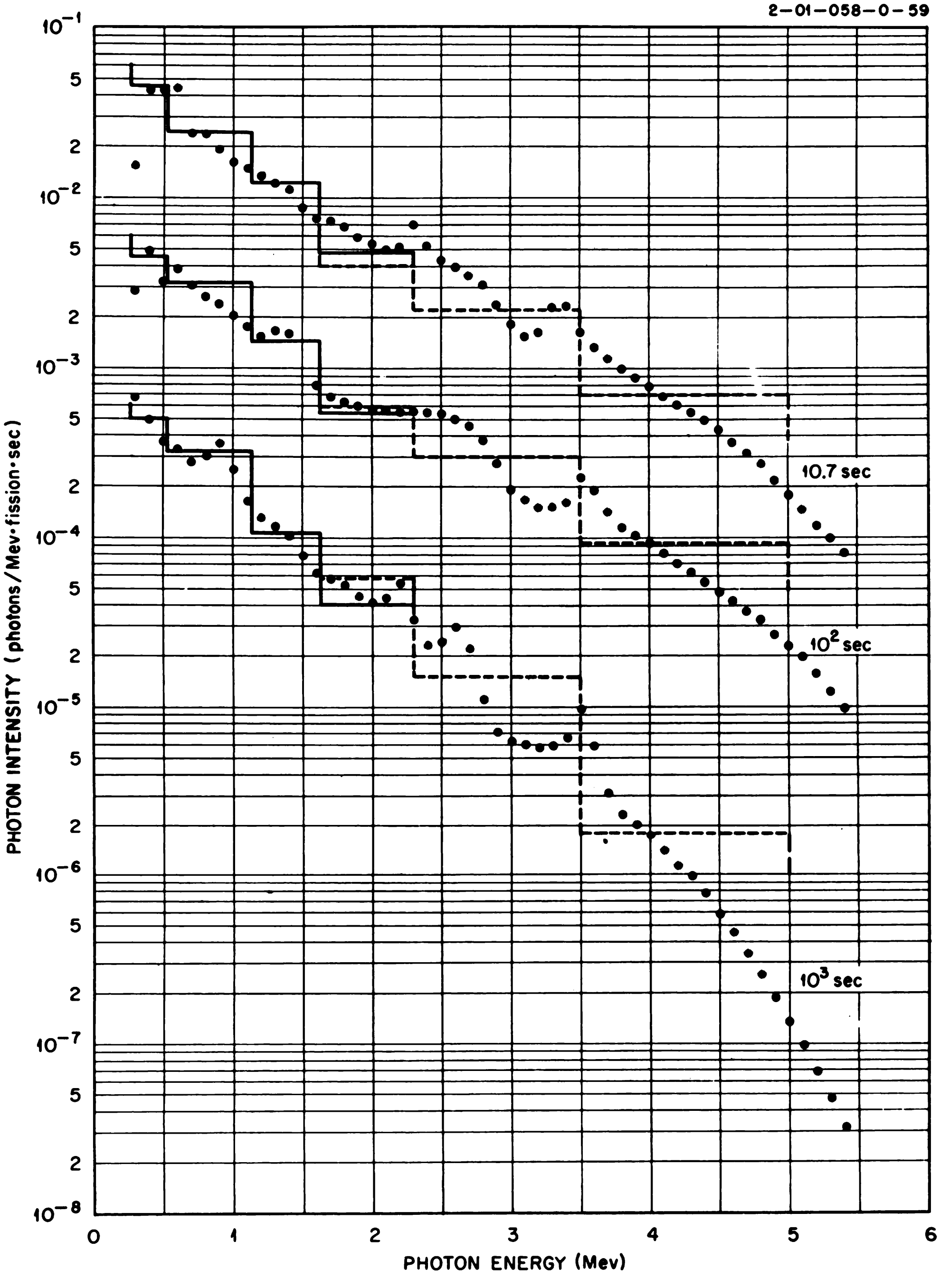

FIGURE 6

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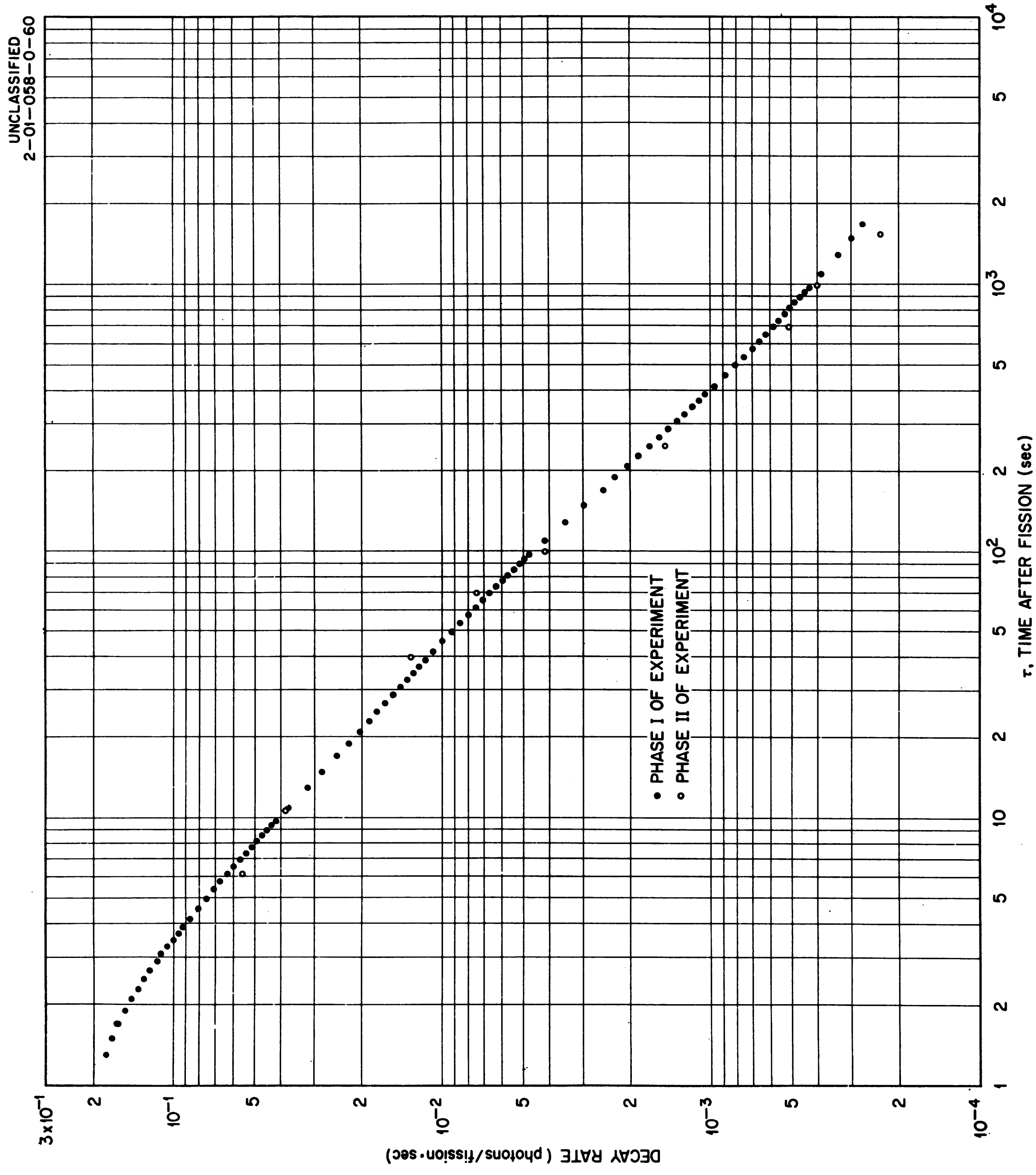

FIGURE 7